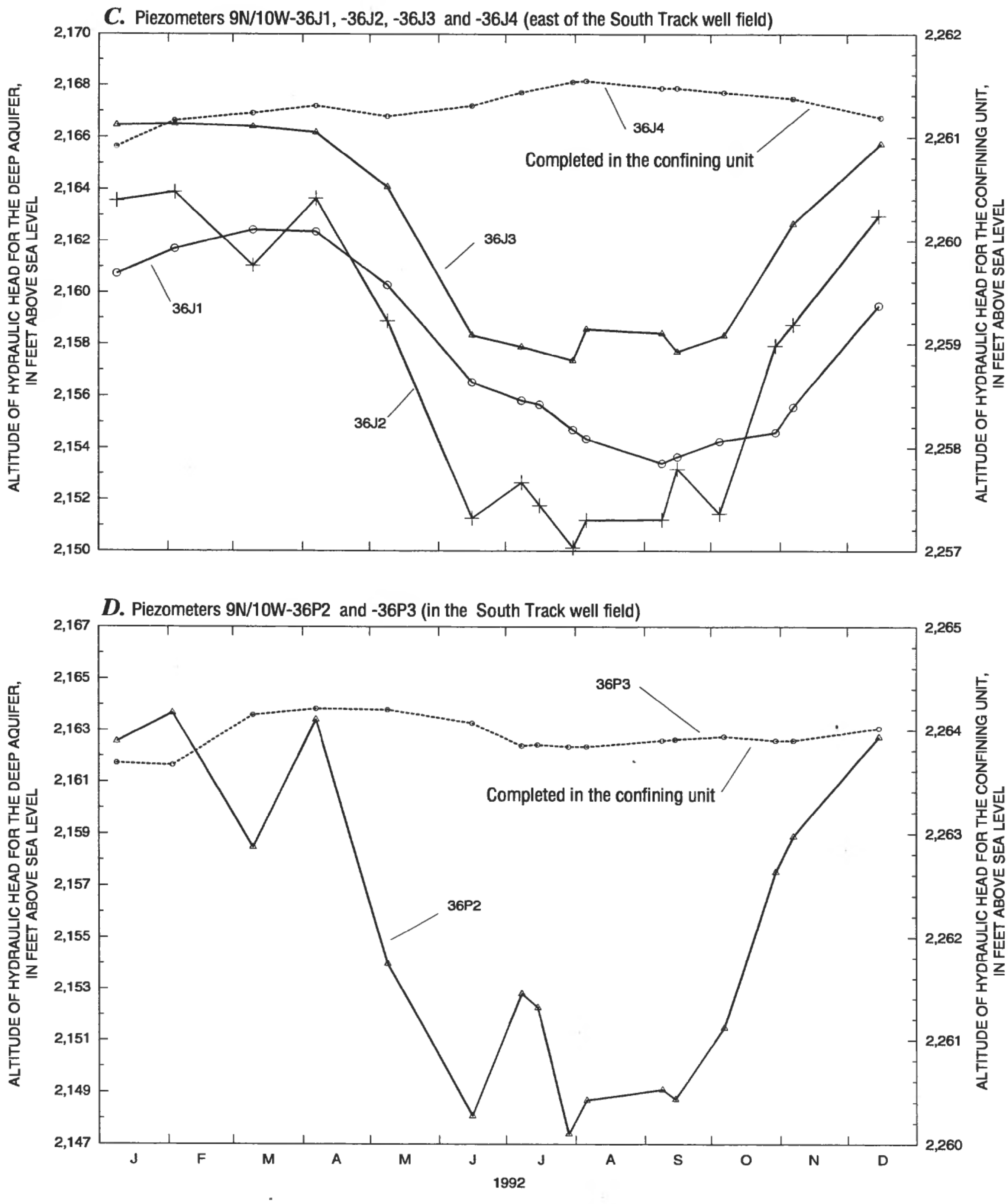
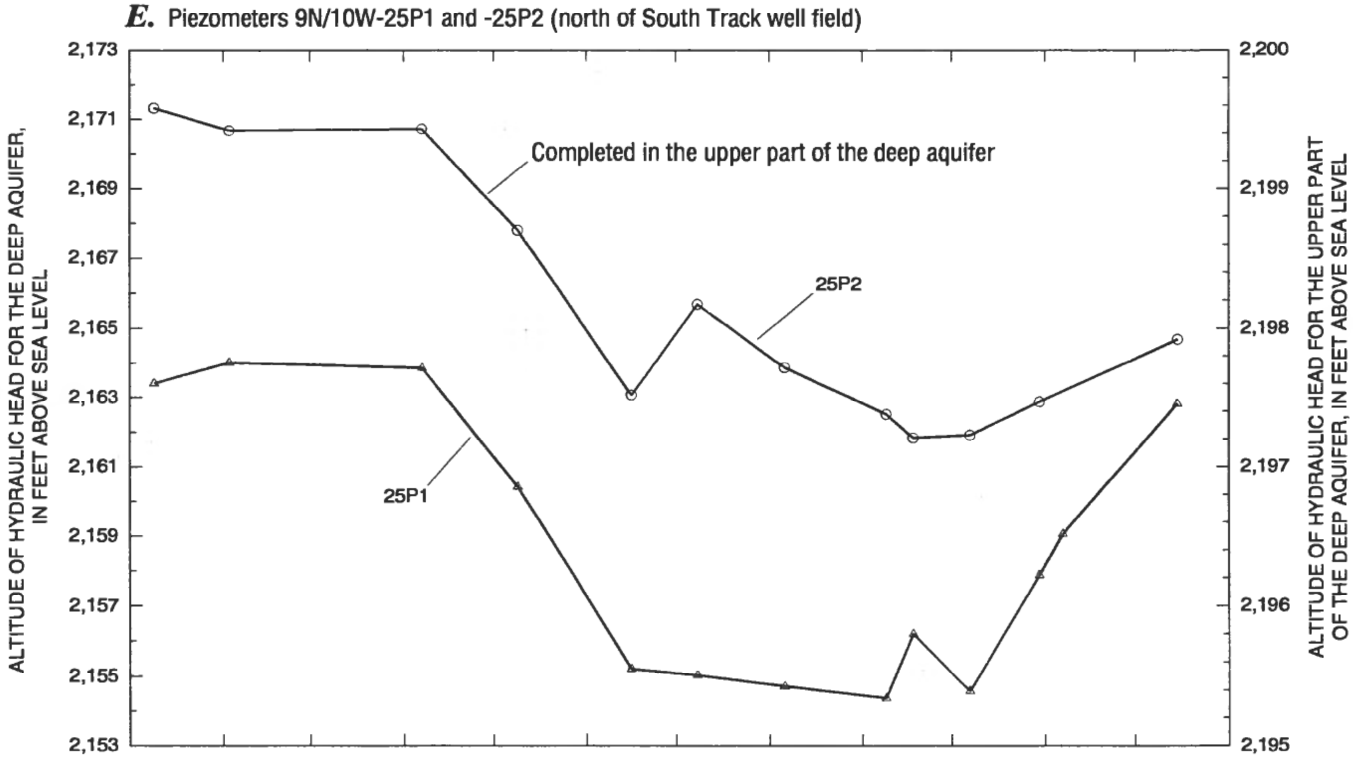


Figure 6. Hydraulic heads for U.S. Geological Survey piezometers on Edwards Air Force Base, California, 1992--*Continued.*



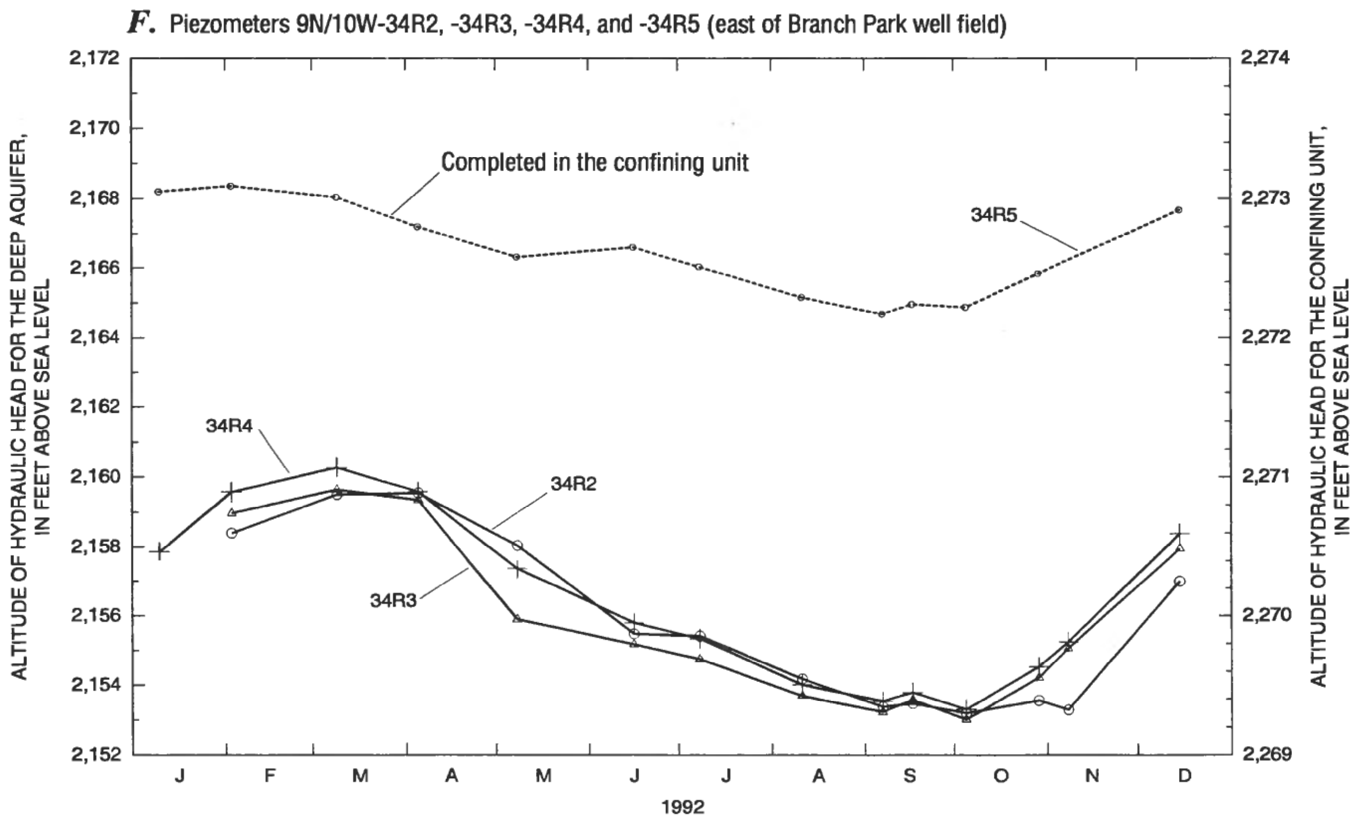


Figure 6. Hydraulic heads for U.S. Geological Survey piezometers on Edwards Air Force Base, California, 1992--*Continued.*

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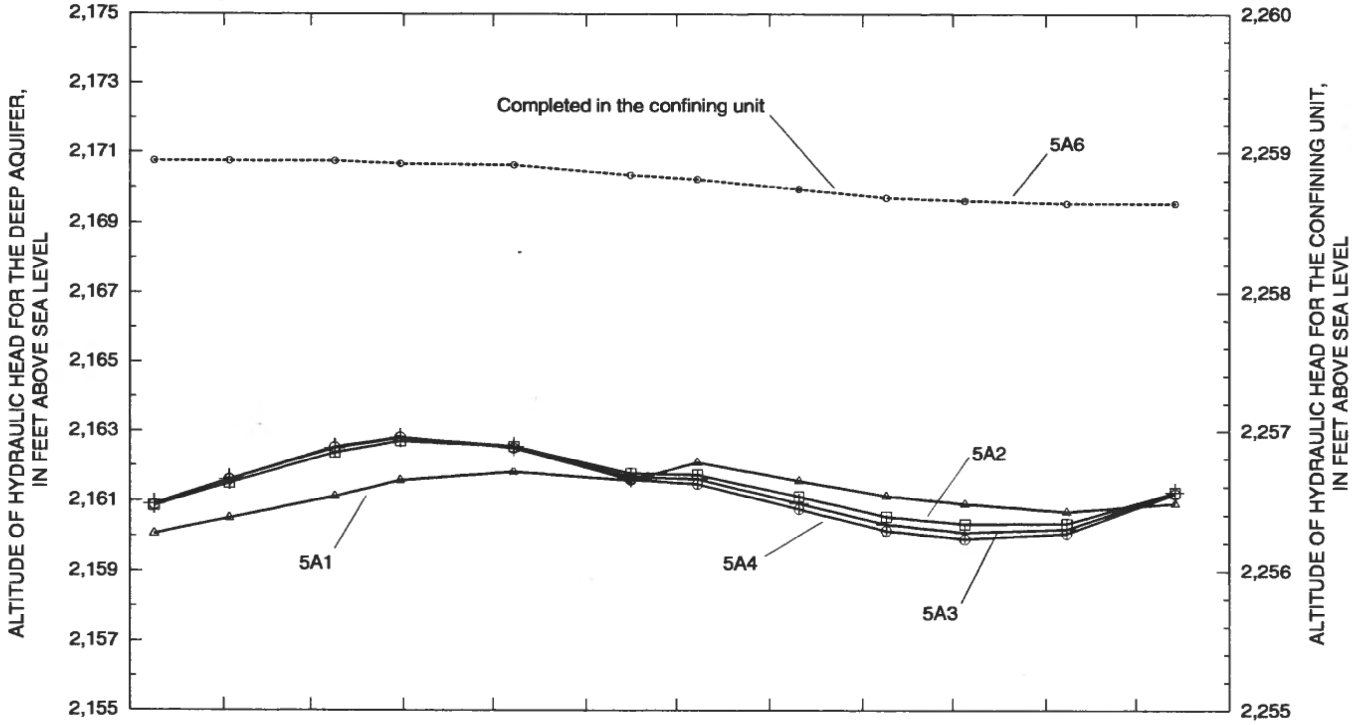
G. Piezometers 8N/10W-5A1, -5A2, -5A3, -5A4, and -5A6 (west of Branch Park well field)



H. Piezometers 9N/10W-28H3 and -28H4 (northwest of Branch Park well field)

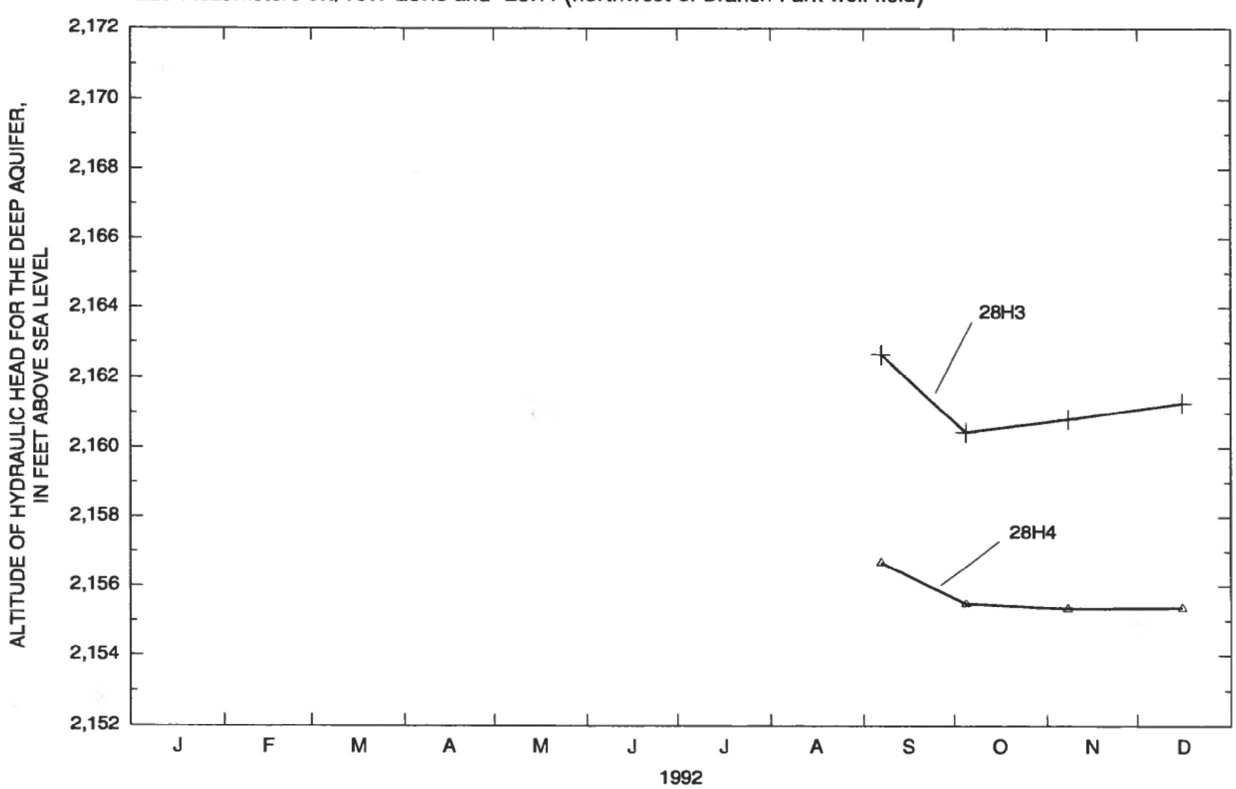
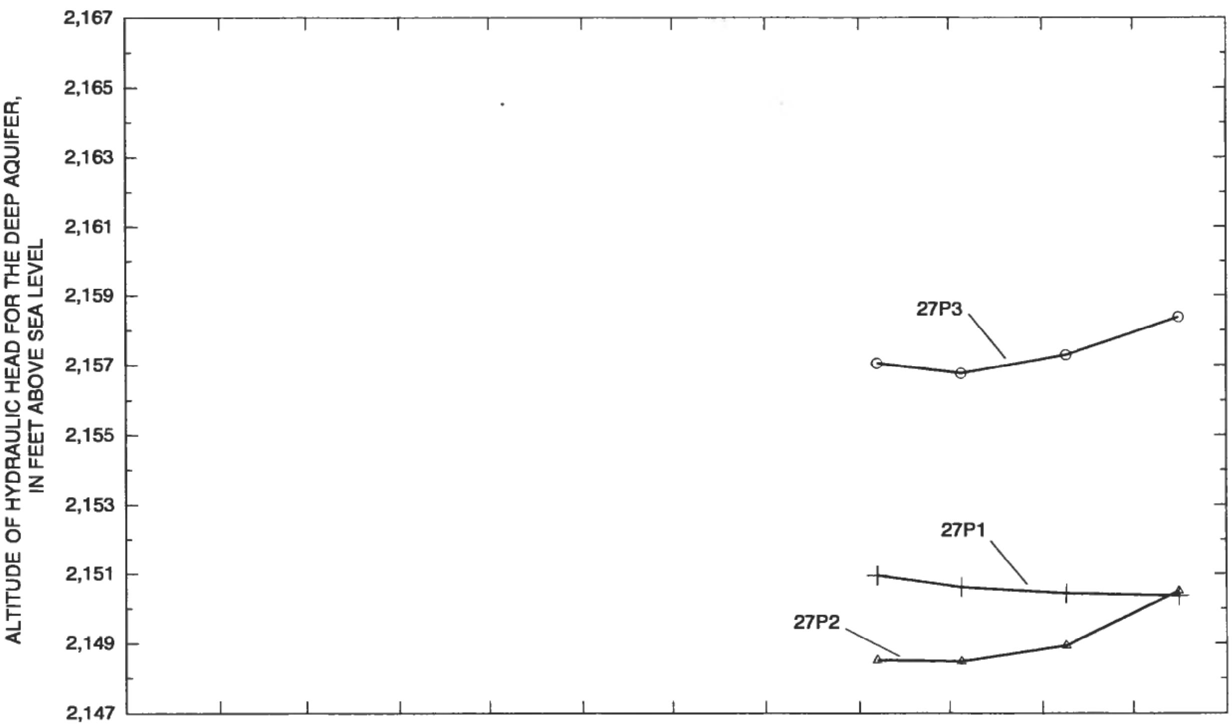


Figure 6. Hydraulic heads for U.S. Geological Survey piezometers on Edwards Air Force Base, California, 1992--*Continued.*

I. Piezometers 9N/10W-27P1, -27P2, and -27P3 (north of Branch Park well field)



J. Piezometers 9N/9W-28A1, -28A2, -28A3, -28A4, and -28A5 (southwest of the Phillips Laboratory well field)

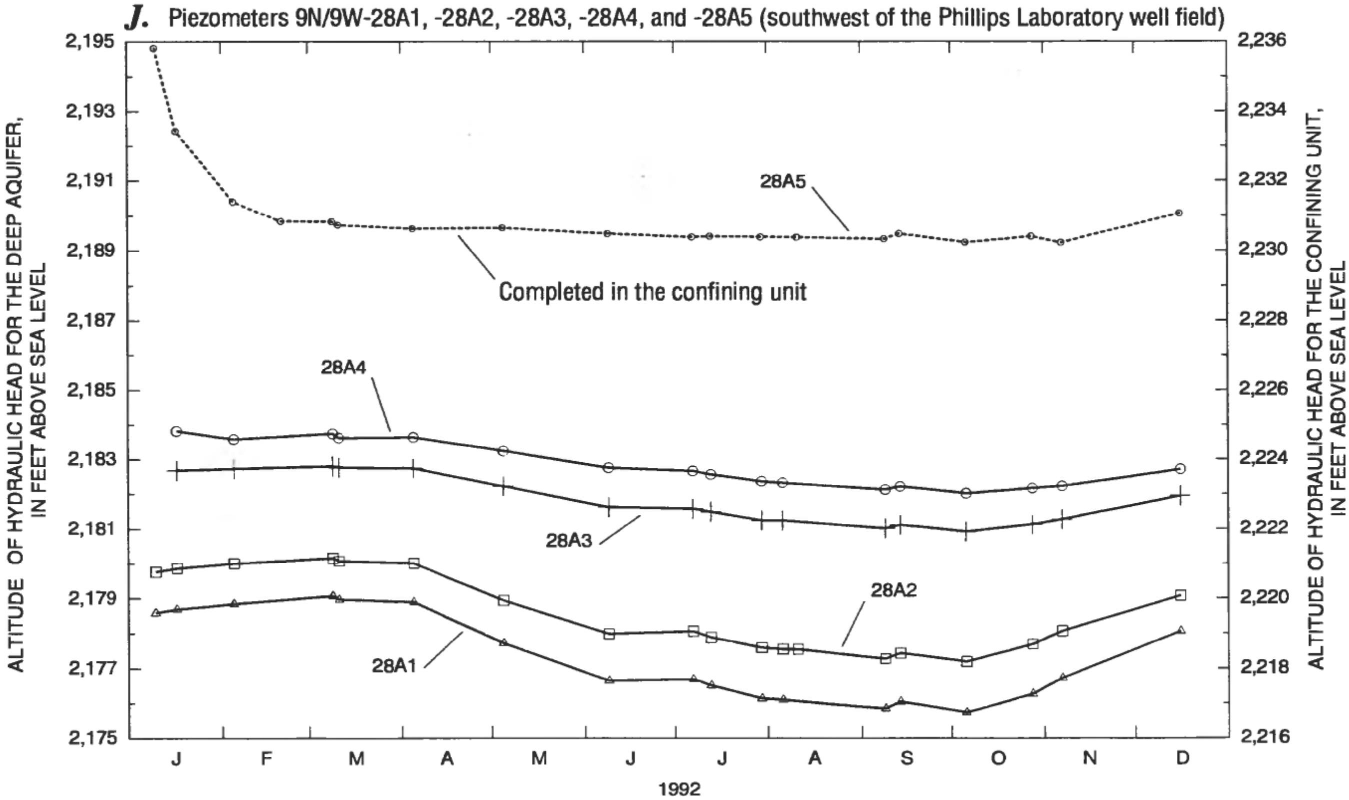
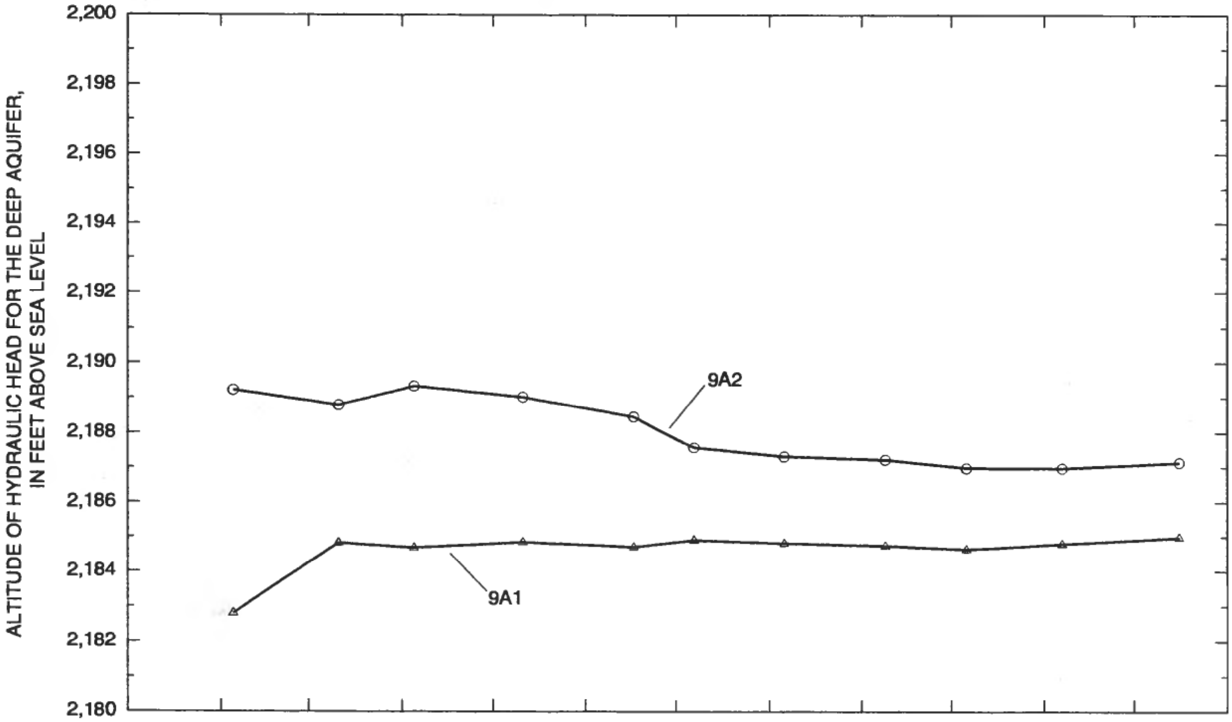


Figure 6. Hydraulic heads for U.S. Geological Survey piezometers on Edwards Air Force Base, California, 1992--*Continued.*

K. Piezometers 9N/9W-9A1 and -9A2 (northwest of the Phillips Laboratory well field)



L. Piezometers 10N/9W-27C1,-27C2, and -27C3 (north of the Phillips Laboratory well field near the ground-water divide)

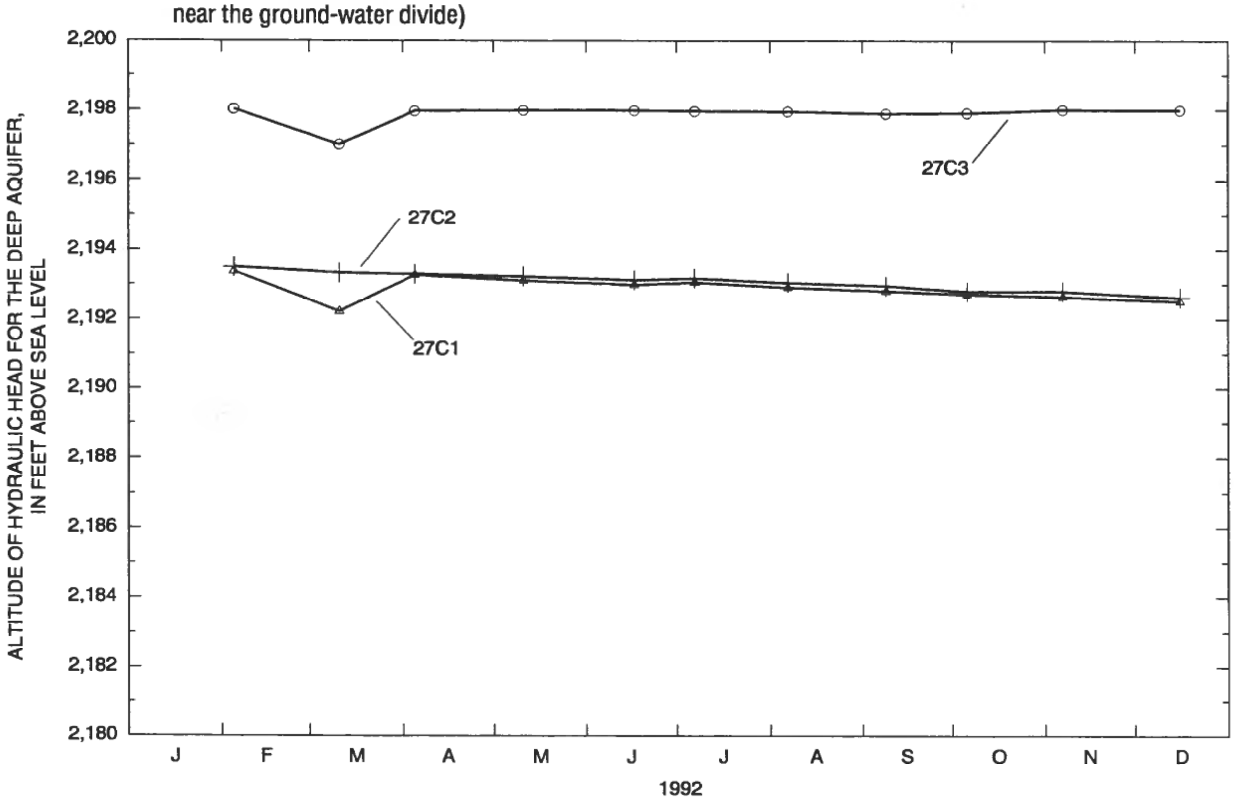
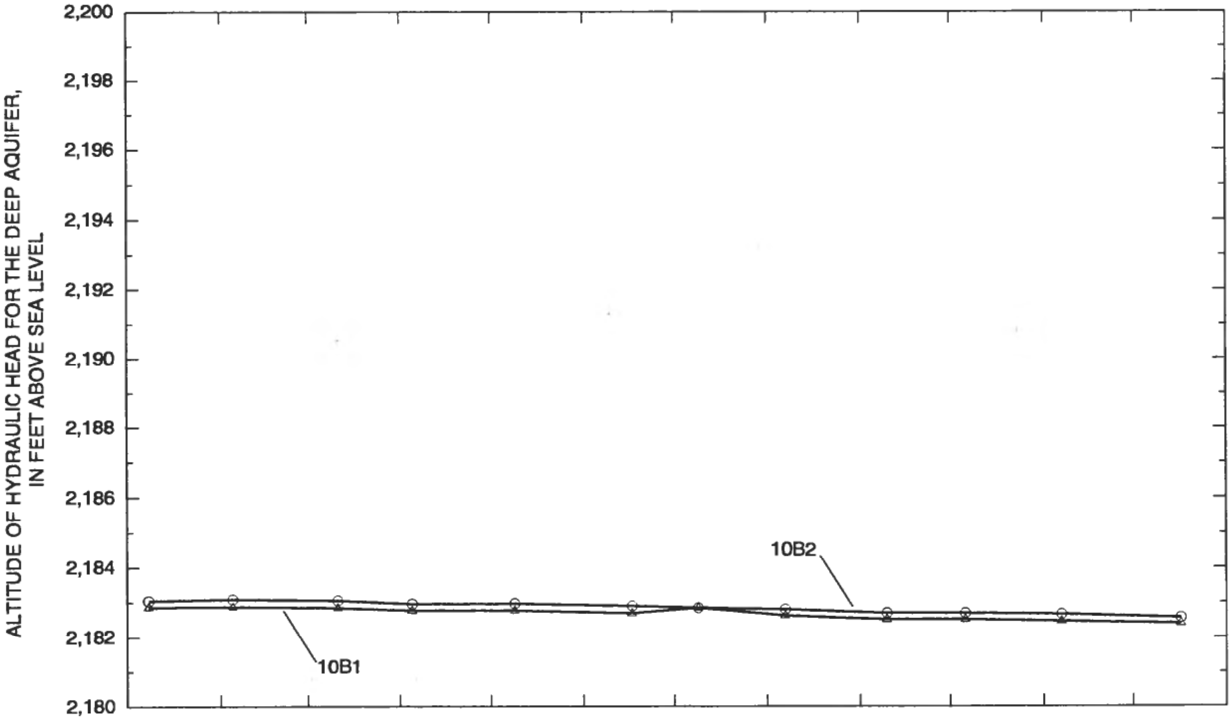


Figure 6. Hydraulic heads for U.S. Geological Survey piezometers on Edwards Air Force Base, California, 1992--*Continued.*

M. Piezometers 10N/9W-10B1 and -10B2 (southeast of the North Base well field)



N. Piezometers 9N/10W-16F1 (north of Graham Ranch well field) and 9N/10W-16R1, -16R2, and -16R3 (in the Graham Ranch well field)

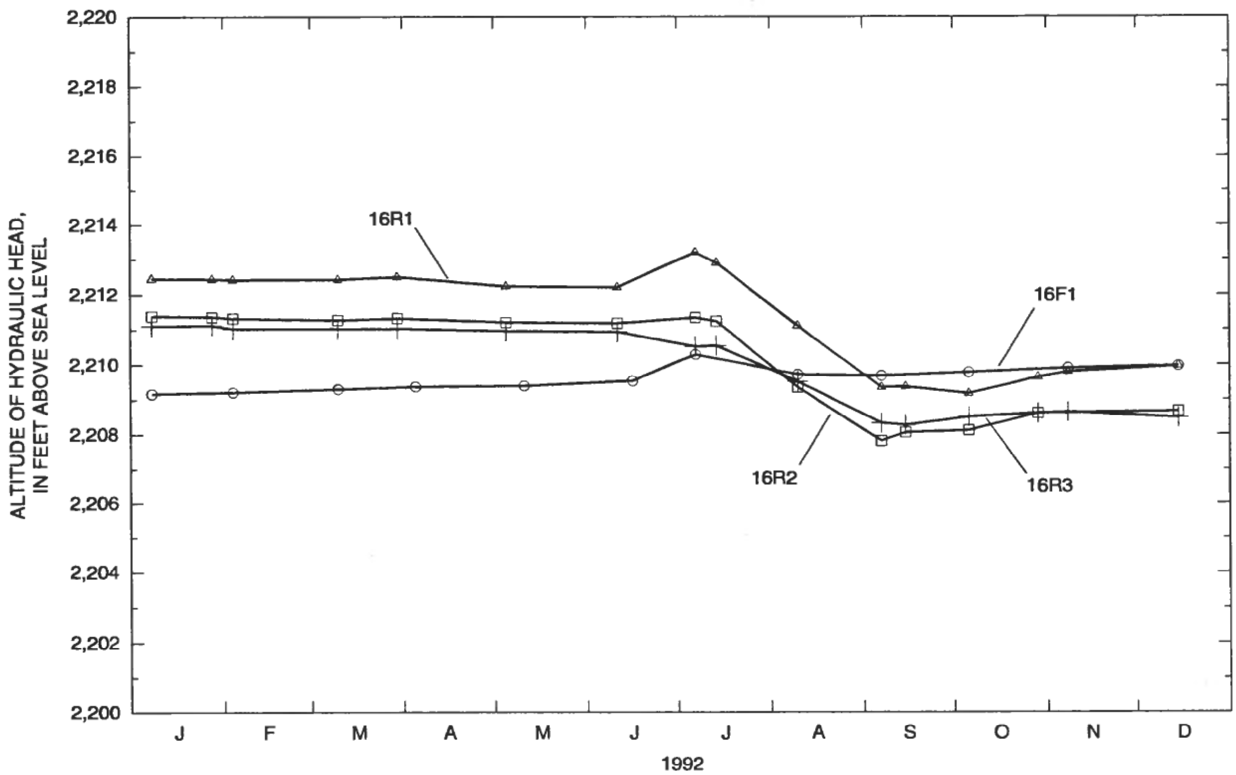


Figure 6. Hydraulic heads for U.S. Geological Survey piezometers on Edwards Air Force Base, California, 1992--*Continued.*

aquifer near the South Track well field (fig. 5) range from about 5 to 15 ft between spring recovery and late summer drawdown levels (figs. 6*A* through 6*N*). Heads in piezometers 8N/10W-1Q1 through -1Q3 and -4R1 through -4R4, 9N/10W-36J1 through -36J3, -36P2, and -34R2 through -34R4 (figs. 6*A*, 6*B*, 6*C*, 6*D*, and 6*F*) are higher than the lower contact of the confining unit (Londquist and others, 1993; Rewis, 1993) indicating confined, nonflowing artesian conditions west, south, and east of the South Track well field. Heads in piezometers 9N/10W-25P1 and -25P2 and 9N/9W-28A1 through -28A4 (figs. 6*E* and 6*J*) are lower than the lower contact of the confining unit indicating unconfined aquifer conditions north of the well field.

On the basis of ground-water-level, lithologic, water-quality, and borehole-resistivity data for piezometer 8N/10W-1Q1, Londquist and others (1993, p. 66) suggest that there is a poor hydraulic connection between the upper and lower confined zones of the deep aquifer at that site. This poor connection may be due to consolidation of the deeper alluvium. Heads in piezometers 8N/10W-4R1, 9N/10W-36J1, 9N/10W-34R2, and 9N/10W-5A1 (figs. 6*B*, 6*C*, 6*F*, and 6*G*) which are completed below 1,500 ft above sea level in the deep aquifer have similar delays in response to seasonal recharge and discharge stresses as for piezometer 8N/10W-1Q1 (fig. 6*A*). This similarity indicates that these piezometers may be completed in the lower confined zone.

Piezometers 8N/10W-4R5, -4R6, -5A6, 9N/9W-28A5, 9N/10W-34R5, -36J4, and -36P3 were completed in the confining unit (table 1, figs. 6*B*-6*D*, 6*F*, 6*G*, and 6*J*). Heads in piezometers 8N/10W-4R5, -4R6, and 9N/9W-28A5 indicate little or no head change from April to September (figs. 6*B* and 6*J*). Heads in piezometers 8N/10W-1Q4, -5A6, 9N/10W-34R5, and -36P3 declined about 0.3, 0.2, 0.6, and 0.3 ft, respectively, from April to September (table 2, figs. 6*A*, 6*G*, 6*F*, and 6*D*). Except for piezometer 8N/10W-1Q4 (fig. 6*A*), these declines correspond to declines in heads in the piezometers completed in the deep aquifer at these sites. Head in piezometer 9N/10W-36J4 increased about 0.2 ft from April to September (table 2, fig. 6*C*). The cause for this increase in head is not known, but may be due to underflow from a nearby dry wash or possibly leakage from water-supply lines in the area.

Piezometer 8N/10W-1Q4 was completed partly in the confining unit and partly in the overlying alluvium (tables 1 and 4) (Londquist and others, 1993). Hydraulic head in this piezometer was about 2,249 ft above sea level in January 1992 and is representative of the hydraulic head in the principal aquifer (fig. 6*A*; table 2). The occurrence of the thin (approximately 40-foot thick) principal aquifer at this site indicates a possibility that the principal aquifer extends into the South Track well-field area. About 3 mi west of well 8N/10W-1Q4 at wells 8N/10W-4R1 through -4R6, the top of the confining unit is about 20 ft higher than the hydraulic head in well -1Q4 (Londquist and others, 1993; Rewis, 1993) indicating a discontinuity of the principal aquifer in this part of the Lancaster subbasin.

The June 28, 1992, Landers and Big Bear earthquakes caused a static strain step (compressional) at EAFB as interpreted from hourly ground-water-level data recorded for piezometers 8N/10W-1Q2, 9N/9W-28A5, and 9N/10W-16R2 (D.L. Galloway, U.S. Geological Survey, written commun., 1992; Galloway, 1993; E. Roeloffs, U.S. Geological Survey, written commun., 1994). This strain step resulted in a volume compression of the aquifer materials, which caused an abrupt rise in hydraulic heads throughout the aquifer system. Heads recovered to near their pre-earthquake levels in the subsequent days or weeks. In some cases, strong pumping influences in the aquifer overwhelmed the aquifer response to the static strain step. The rise in heads between June and July recorded for piezometers 8N/10W-1Q4, 8N/10W-4R6, 9N/10W-25P2, 8N/10W-5A1, 9N/9W-9A1, -28A1, -28A2, 10N/9W-27C1, -27C2, 9N/10W-16F1, -16R1, and -16R2 (figs. 6*A*, 6*B*, 6*E*, 6*G*, 6*J*, 6*K*, 6*L*, and 6*N*) may reflect the same abrupt rise and subsequent decline response as those reported by Galloway (1993) and E. Roeloffs (U.S. Geological Survey, written commun., 1994).

Pumpage and Hydraulic Heads in Production Well Fields

Seven production well fields (fig. 5) provide potable and nonpotable water at EAFB. South Track, South Base, and North Base well fields provide potable water to the main facilities of the base. Branch Park and Graham Ranch well fields provide nonpotable water for landscape and recreational uses. The two Phillips Laboratory well fields supply potable ground water for potable and nonpotable uses for that facility.

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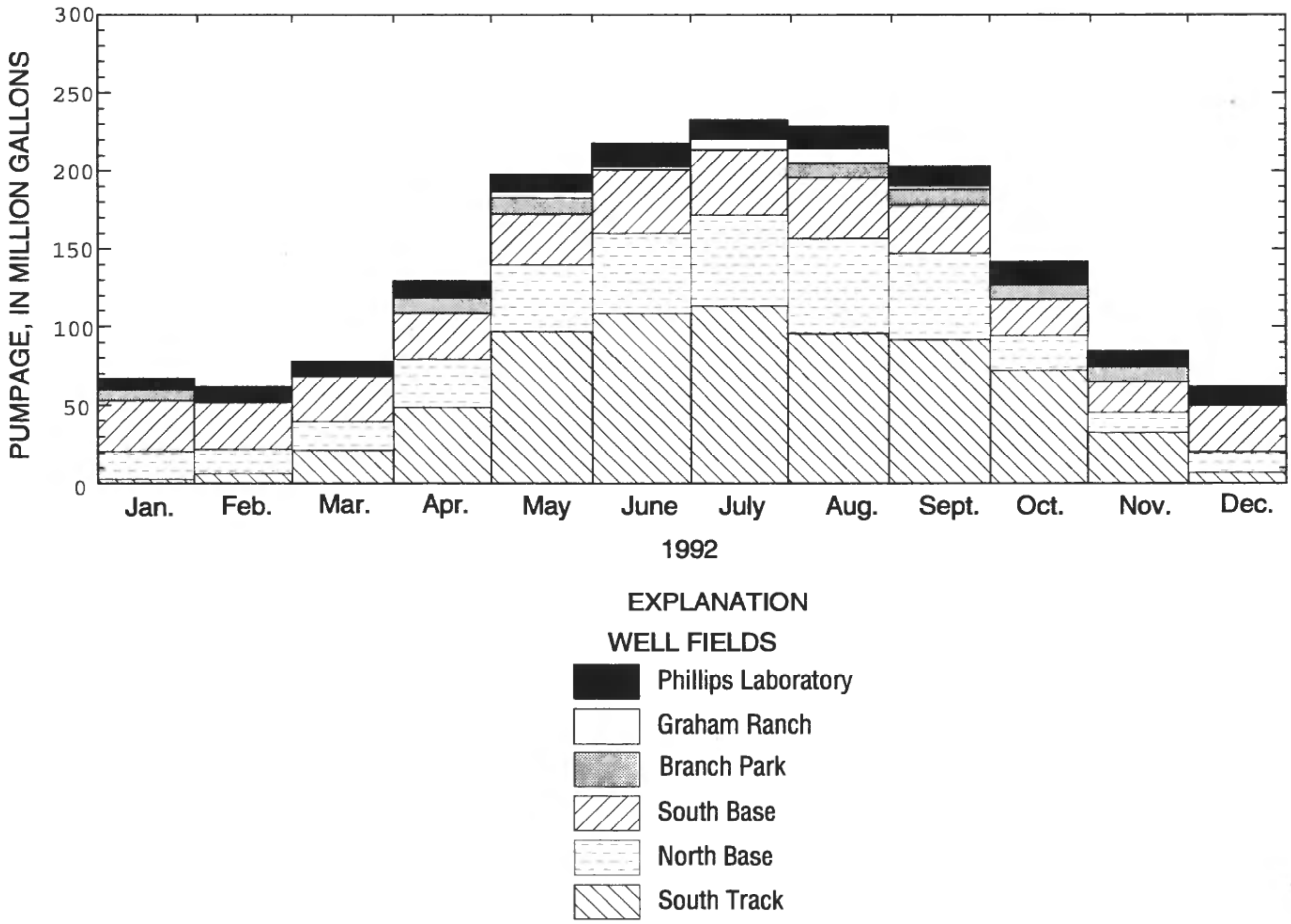

Figure 7. Total monthly pumpage at Edwards Air Force Base, California. (See table 3 for pumpage values.)

The production wells in the South Track, South Base, Branch Park, and Phillips Laboratory well fields yield water from the deep aquifer of the Lancaster subbasin, and the production wells in the North Base well field yield water from the unconfined aquifer of the North Muroc subbasin. Production wells in the Graham Ranch well field yield water from an unconfined aquifer in a small isolated subbasin. Total base pumpage for EAFB in 1992 was about 1,700 million gal, or 5,225 acre-ft (table 3) (Ronald Johnson, Edwards Air Force Base, written commun., 1993; C. Singletary, Superintendent of Water and Waste, Civil Engineering, Phillips Laboratory, Edwards Air Force Base, written commun., 1993). Figure 7 is a bar graph that illustrates the seasonal fluctuations of monthly pumpage totals for the well fields presented in table 3.

South Track Well Field

Total pumpage for 1992 for the South Track well field was about 697.3 million gal, 2,140 acre-ft (table 3). Hydrographs for wells and selected piezometers in and near the South Track well field and total monthly pumpage for wells 8N/10W-1C2 (S-6), 9N/10W-36F1 (S-4), and -36P1 (S-5) are shown in figure 8. During winter and early spring recovery, pumpage was low and hydraulic heads were about 2,164 to 2,166 ft above sea level. From April to May, pumpage doubled and heads began to decline (fig. 8). Pumping was nearly continuous from May into October. From April to September, heads declined about 9 ft in piezometers 8N/10W-1Q3 and 9N/10W-25P1 and about 10 ft in wells 9N/10W-36F1 and 8N/10W-1C2. Draw-

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Table 3. Monthly and annual pumpage data from production wells on Edwards Air Force Base, California, 1992

[State well No.: See well-numbering system in text. See figure 5 for locations of wells. n/o, pump not operational; Mgal,

State well No.	Base well identification No.	Pumpage, in million gallons					
		January	February	March	April	May	June
South Track well field							
8N/10W-1C2	S-6	1.017	2.343	3.671	8.716	41.609	6.925
9N/10W-36F1	S-4	.415	3.988	5.064	30.782	10.589	42.034
-36P1	S-5	1.336	0	12.723	9.277	44.751	59.458
	Total	2.768	6.331	21.458	48.775	96.949	108.417
North Base well field							
10N/9W-5B1	N-2	17.573	15.469	17.596	30.111	42.917	51.553
	Total	17.573	15.469	17.596	30.111	42.917	51.553
South Base well field							
9N/10W-24E2	S-3	0	0	0	0.908	3.013	13.340
-24G1	S-2	32.627	29.952	29.464	28.629	29.394	27.366
	Total	32.627	29.952	29.464	29.537	32.407	40.706
Branch Park well field							
9N/10W-34P3	C-1	6.925	0	0	10.121	10.212	1.886
	Total	6.925	0	0	10.121	10.212	1.886
Graham Ranch well field							
9N/10W-16P1	C-3	0.057	0.063	0.019	0.328	4.249	0.992
-16R4	C-4	n/o	n/o	n/o	n/o	n/o	n/o
	Total	0.057	0.063	0.019	0.328	4.249	0.992
Phillips Laboratory well fields							
9N/9W-14P2	Well B	2.442	1.123	2.758	2.628	2.457	4.748
-15J1	Well A	1.176	3.784	1.603	3.058	2.233	2.748
-13N1	Well D	n/o	n/o	n/o	n/o	.421	.278
-14Q1	Well C	1.981	2.771	2.448	2.423	2.473	3.170
9N/8W-6J1	MW-3	1.516	2.180	2.196	2.535	3.378	3.145
	Total	7.115	9.858	9.005	10.644	10.962	14.089
Monthly base total, million gallons......................................		67.065	61.673	77.542	129.516	197.696	217.643
Monthly base total, acre-feet..		205.8	189.2	237.9	397.4	606.6	667.8

[1]Flowmeter not operational, pumpage estimated using number of hours operated at 1,700 gallons per minute.

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million gallons; acre-ft, acre-foot]

Pumpage, in million gallons--*Continued*						Annual well and well field totals (Mgal)	Annual well field total (acre-ft)
July	August	September	October	November	December		
0	0.00	2.542	4.920	2.023	4.358	78.124	
56.054	53.576	31.404	19.377	5.303	2.615	261.201	
57.330	42.073[1]	57.907[1]	47.868	25.214[1]	n/o	357.937	
113.384	95.649	91.853	72.165	32.540	6.973	697.262	2,139.6
58.116	60.812	55.149	21.988	12.757	13.140	397.181	
58.116	60.812	55.149	21.988	12.757	13.140	397.181	1,218.7
14.092	11.434	5.119	10.289	7.831	1.876	67.902	
27.841	28.048	25.883	13.133	11.629	27.819	311.785	
41.933	39.482	31.002	23.422	19.460	29.695	379.687	1,165.0
0.00	8.869[1]	10.060	9.359	9.394	0.741	67.567	
0.00	8.869	10.060	9.359	9.394	0.741	67.567	207.3
n/o	n/o	0	0.075	0	0	5.783	
7.074	9.712	2.468	0	.825	.362	20.441	
7.074	9.712	2.468	0.075	0.825	0.362	26.224	80.5
3.018	2.784	2.035	2.210	1.346	1.494	29.043	
1.136	3.121	2.371	3.770	1.984	2.590	29.574	
2.797	3.719	3.295	3.725	2.162	2.881	33.529	
4.432	2.984	3.500	2.801	1.940	2.762	19.118	
.758	1.314	1.241	2.406	1.751	.925	23.661	
12.141	13.922	12.442	14.912	9.183	10.652	134.925	414.0
232.648	228.446	202.974	141.921	84.159	61.563	1,702.846	
713.9	701.0	622.8	435.5	258.2	188.9	5,255.1	

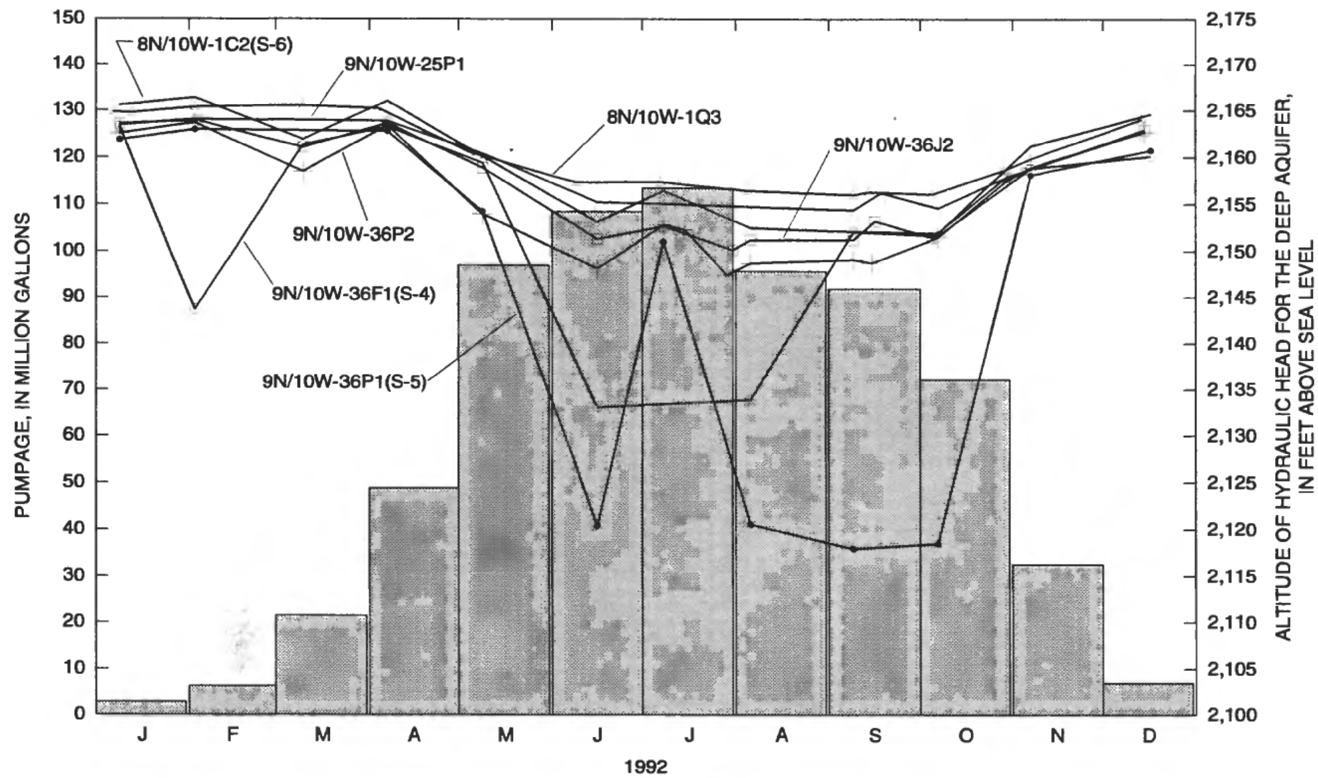

Figure 8. Monthly pumpage from and hydraulic heads in wells and selected piezometers in and near the South Track well field, Edwards Air Force Base, California.

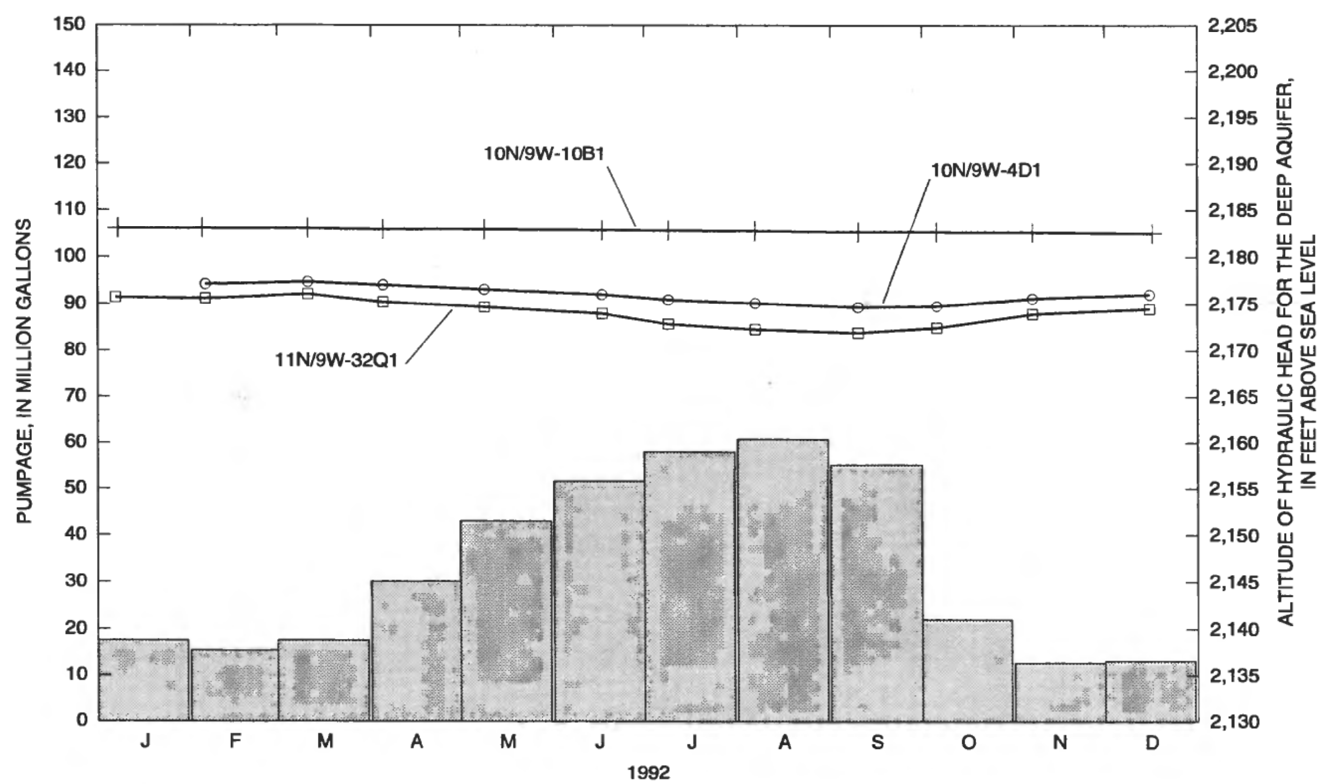

Figure 9. Monthly pumpage from and hydraulic heads in wells and selected piezometers in and near the North Base well field, Edwards Air Force Base, California.

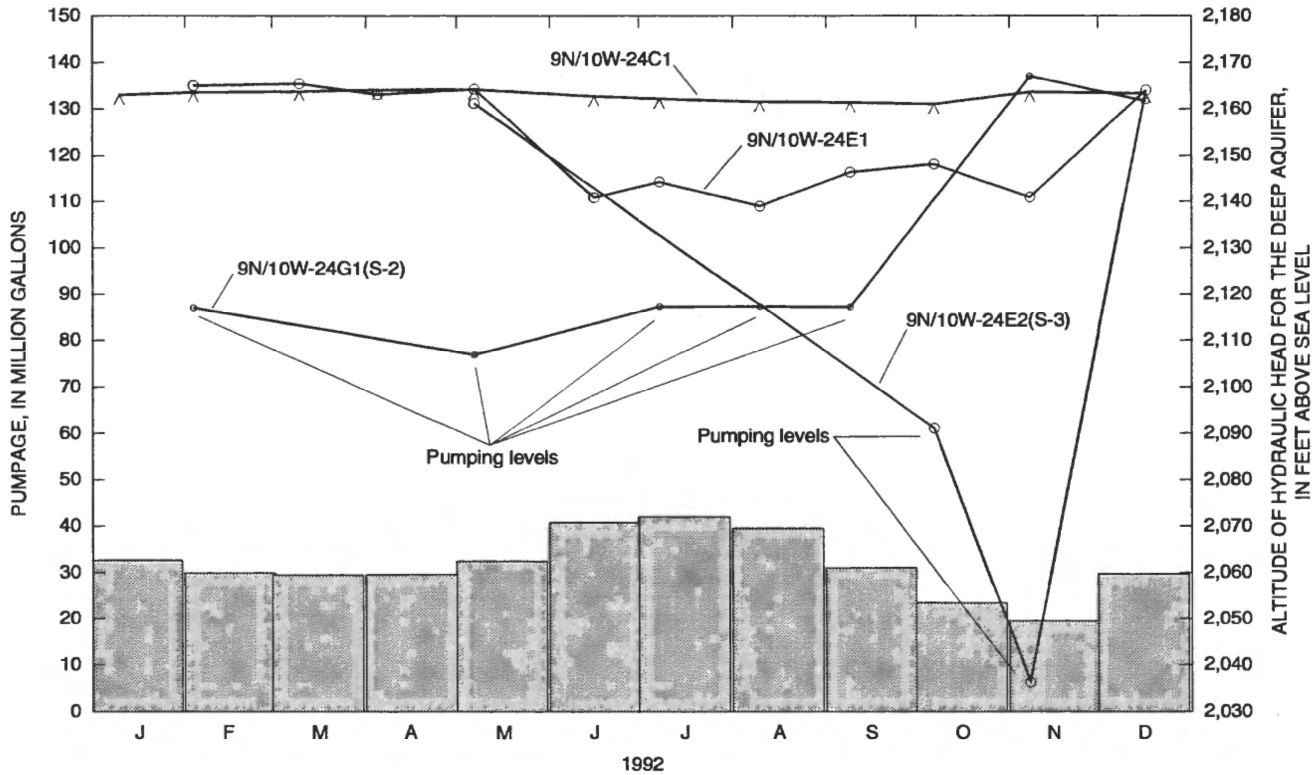

Figure 10. Monthly pumpage from and hydraulic heads in wells in the South Base well field, Edwards Air Force Base, California.

downs were about 20 ft and 30 ft in wells 9N/10W-36F1 and 9N/10W-36P1, respectively. Recovery began in late October, and by early December, heads recovered to about 2,160 to 2,165 ft above sea level.

North Base Well Field

About 397.2 million gal, or 1,219 acre-ft, was pumped from well 10N/9W-5B1 in the North Base well field (fig. 5) in 1992 (table 3). From April to September 1992, hydraulic heads declined about 2 ft in well 10N/9W-4D1 to the east of well 10N/9W-5B1 and about 3 ft in well 11N/9W-32Q1 to the north of well 10N/9W-5B1 (fig. 9). By December, well 10N/9W-4D1 had recovered 1.3 ft and well 11N/9W-32Q1 had recovered 2.2 ft. Heads in piezometer 10N/9W-10B1, about 2.2 mi southeast of well 10N/9W-5B1, declined steadily about half a foot during an 11-month period (January 8 to December 17, 1992).

South Base Well Field

Total annual pumpage for the South Base well field (fig. 5) in 1992 was about 379.7 million gal, 1,165 acre-ft (table 3), with an average monthly total of about 31.6 million gal, 97 acre-ft. The hydrograph for well 9N/10W-24C1 (fig. 10) shows that hydraulic heads ranged from about 2,164 to 2,167 ft above sea level. The altitude scale in figure 10 is two times that of figures 8 and 9. Drawdowns ranged about 50 to 60 ft for well 9N/10W-24G1 (S-2) and about 70 to 130 ft for 9N/10W-24E2 (S-3). Well 9N/10W-24E1 is about 750 ft north of well 9N/10W-24E2 (fig. 5). The 10-foot drop in head in well 9N/10W-24E1 when well -24E2 (S-3) was being pumped indicates that -24E1 is in the cone of depression of -24E2. Large drawdowns in both production wells may be due to low transmissivities (Londquist and others, 1993, tables 7 and 8) in this area or may indicate loss of storage in the aquifer because of dewatering and compaction of the interbedded, fine-grained layers. Large drawdowns allow an increase in oxidation or corrosion of the steel well casing when it is exposed to air, which could lead to collapse or shearing of the well casing. Such corrosion may have contributed to the collapse of well 9N/9W-18C1 (S-1) in 1991. The cement pump pad for well 9N/10W-24E2 was cracked and the cement foundation

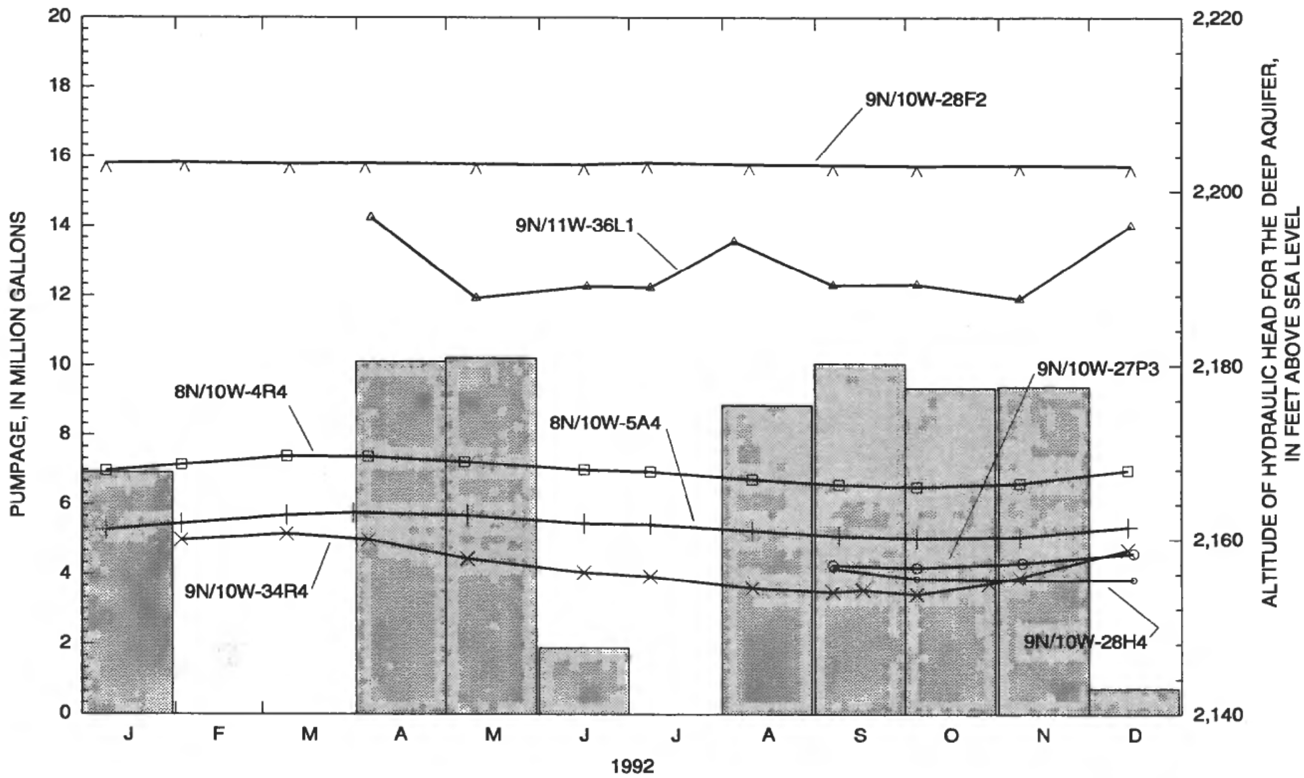

Figure 11. Monthly pumpage from and hydraulic heads in wells and selected piezometers in and near the Branch Park well field, Edwards Air Force Base, California.

had broken away from the bottom of the pad about 1 to 2 in., which indicates land subsidence and surface deformation have occurred around this well.

Branch Park Well Field

The Branch Park well field is about 1.5 mi west of the South Track well field (fig. 5). About 67.6 million gal, or 207 acre-ft, of ground water was pumped from well 9N/10W-34P3 (C-1) (table 3). The pumpage scale in figure 11 is one-fifth the pumpage scale in figures 8, 9, and 10. Hydraulic head in piezometer 9N/10W-34R4 declined about 7 ft from 2,160 to 2,153 ft above sea level between March and October 1992, then started to recover in late October even though well 9N/10W-34P3 continued to be pumped through November. This fluctuation reflects the influences of the combined pumping stresses occurring in the South Track and Branch Park well fields. Head in well 9N/10W-28F2, about 2 mi to the northwest of the Branch Park well field, was about 2,203 ft above sea level and about 40 to 50 ft higher than heads in piezometers 8N/10W-5A4 and 9N/10W-34R4. Head in well 9N/10W-28F2 did not respond to seasonal pumping stresses (fig. 11). These observations could be explained if well 9N/10W-28F2 were isolated from the aquifer system of the Lancaster subbasin.

Well 9N/11W-36L1, about 4 mi west of the Branch Park well field, is believed to be completed in the deep aquifer. The cause of the erratic ground-water-level fluctuations in this well is unknown (fig. 11). Falling water was heard when water levels were more than 100 ft below land surface, but no sound was heard when water levels were less than 95 ft below surface, which may indicate a perched aquifer in this area. This well may act as a conduit that hydraulically connects the perched and deep aquifers.

Graham Ranch Well Field

About 26.2 million gal, 80 acre-ft, were pumped from wells 9N/10W-16P1 (C-3) and -16R4 (C-4) in the Graham Ranch well field (fig. 5) in 1992 (table 3). Hydraulic heads ranged from about 2,200 to 2,210 ft above sea level (fig. 12). The altitude and pumpage scales in figure 12 are the same scales as those used in figure 11. About 0.3 million gal in April and about 4.2 million gal in May 1992 was pumped from well 9N/

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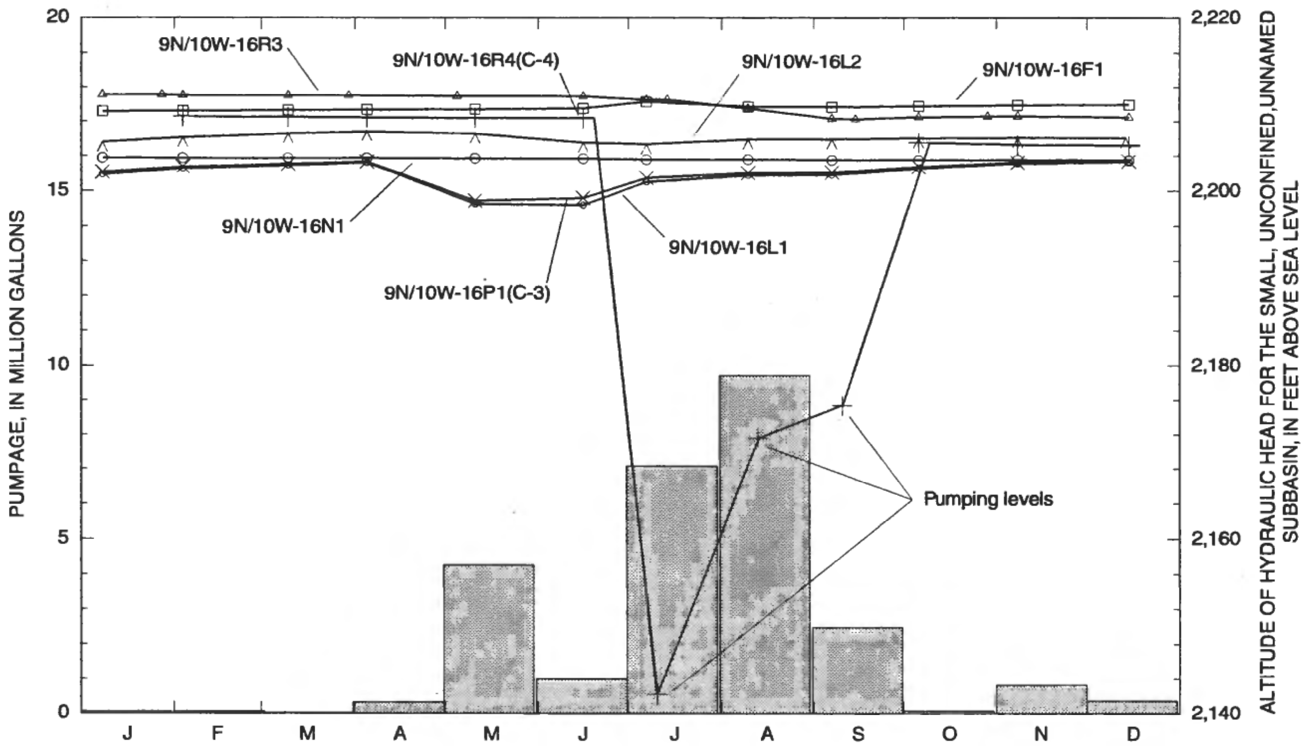

Figure 12. Monthly pumpage from and hydraulic heads in wells and selected piezometers in and near the Graham Ranch well field, Edwards Air Force Base, California.

10W-16P1 (C-3); the heads in wells 9N/10W-16P1 and -16L1 declined about 4.5 ft. Pumping from well 9N/10W-16P1 was ceased on June 30, 1992, and head was slow to recover to prepumping levels. Well 9N/10W-16R4 (C-4), 0.75 mi east of 9N/10W-16P1, was put into production July 1, 1992 (Ronald Johnson, Edwards Air Force Base, written commun., 1992). Drawdowns in well 9N/10W-16R4 ranged from 30 to 65 ft, and recovery in October 1992 was about 3 ft lower than prepumping levels.

Phillips Laboratory Well Fields

The Phillips Laboratory well fields are east of Rogers Lake (fig. 5). Two of the four production wells near the eastern shore of Rogers Lake were monitored, and one production well about 3.5 mi to the northeast was monitored. These well fields produced about 134.9 million gal, or 414 acre-ft, in 1992 (table 3). The pumpage scale in figure 13 is the same scale as the scale used for figures 11 and 12. Hydraulic heads ranged from about 2,182 to 2,191 ft above sea level (fig. 13). The altitude scale in figure 13 is three-fifths the scale used in figures 8, 9, 11, and 12.

Hydraulic heads in well 9N/8W-6J1 declined about 1 ft from January to December 1992; drawdown was about 23 ft. Heads in the wells and piezometers in and near the Phillips Laboratory well fields declined about 1 to 2 ft from January to December. Heads in piezometer 9N/9W-9A2 and production well 9N/9W-15J1 (Well A) declined about 1 ft between June and July (fig. 13) after production well 9N/9W-13N1 (Well D) began being pumped heavily at the end of June (table 3) (C. Singletary, Superintendent of Water and Waste, Civil Engineering, Phillips Laboratory, Edwards Air Force Base, written commun., 1993). This pumping had no influence on heads in wells 9N/9W-10R1 and -27H1 (fig. 13), about 1 mi north and 1.5 mi south of the well field, respectively. The heads in piezometers 9N/9W-9A1 (fig. 6*K*) and 9N/9W-28A1 through -28A4 (fig. 6*J*) also did not respond to

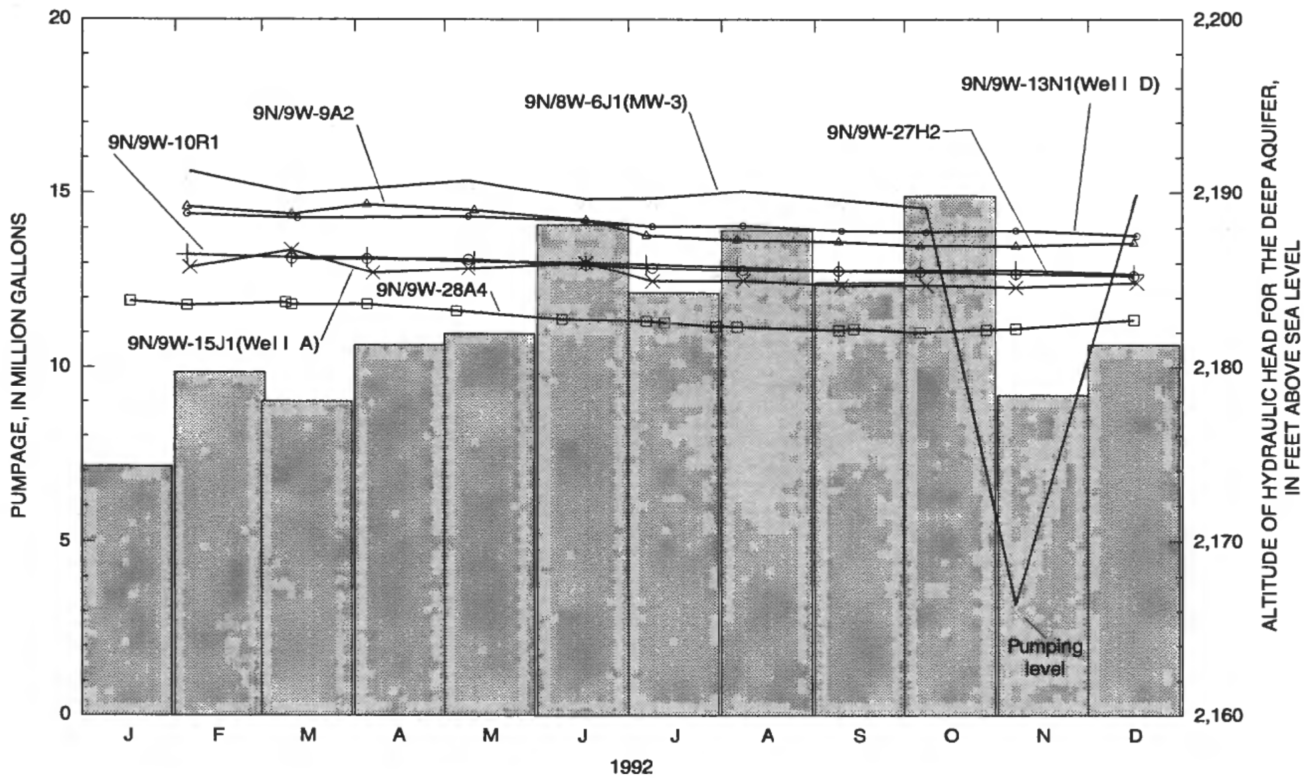

Figure 13. Monthly pumpage from and hydraulic heads in wells and selected piezometers in and near the Phillips Laboratory well fields, Edwards Air Force Base, California.

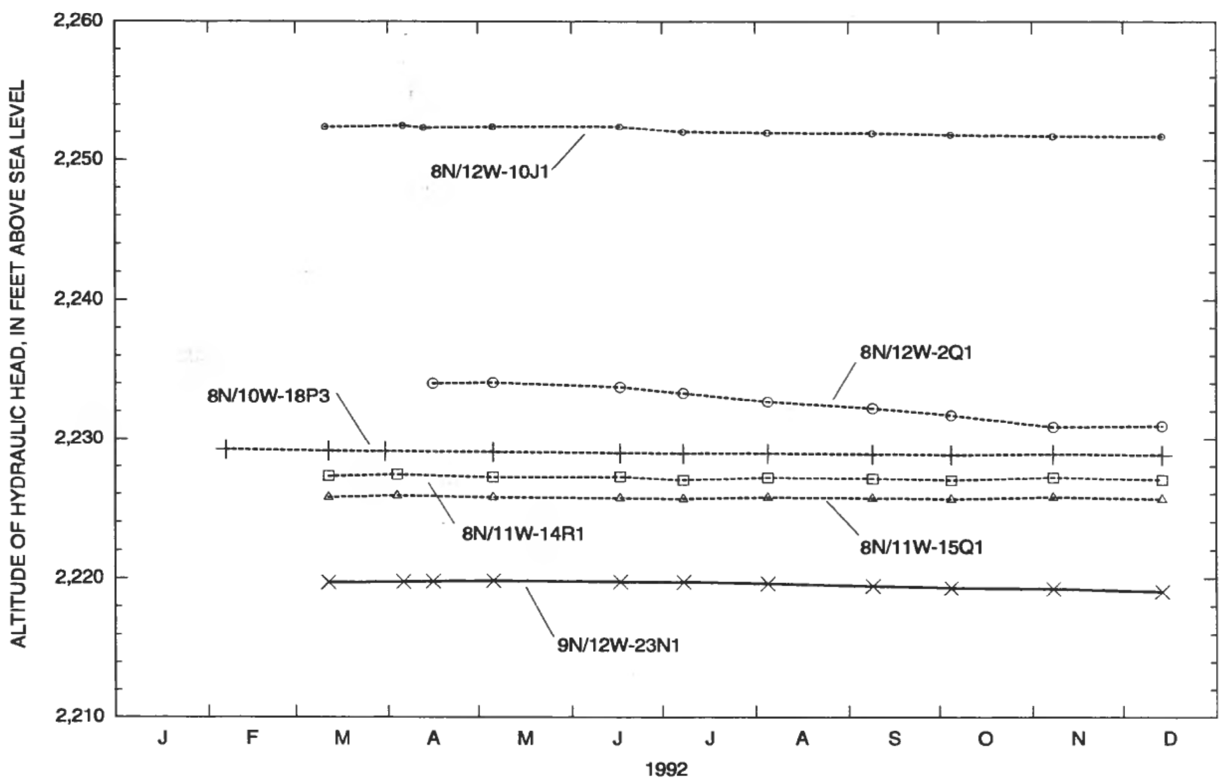

Figure 14. Hydraulic heads in wells south and west of Buckhorn and Rosamond Lakes, Edwards Air Force Base, California.

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the increase in pumping. Piezometer 9N/9W-9A2 and well 9N/9W-15J1 seem to be hydraulically connected to well 9N/9W-13N1, and wells 9N/9W-10R1 and -27H2 and piezometers 9N/9W-9A1 and -28A1 do not seem to be connected. This hydraulic connection between the production wells and piezometer 9N/9W-9A2 may be through channelized, unconsolidated, coarse-grained gravel with high transmissivity, while wells 9N/9W-10R1 and -27H1 may be completed in poorly to moderately consolidated, fine-grained sediments that have lower transmissivities. Further study is needed to understand the variability in transmissivities in this area.

Hydraulic Heads in Wells Southeast and West of Rosamond Lake

Wells 8N/10-18P3, 8N/11W-14R1, -15Q1, 8N/12N-2Q1, and -10J1 (fig. 5) are completed in the principal aquifer (table 1). Hydraulic heads in wells 8N/10W-18P3, 8N/11W-14R1 and -15Q1, and 8N/12W-10J1 (fig. 14) remained relatively static from February and March 1992 through December 1992. Head in well 8N/12W-2Q1 declined about 3 ft from April to November (table 2).

Well 9N/12W-23N1 is near the northwest shore of Rosamond Lake (fig. 5). The location and depth to water of this well suggest that it is completed in the deep aquifer (tables 1 and 2). Heads in this well declined about 0.66 ft between March and December 1992 (table 2, fig. 14). Figure 14 shows heads in well 9N/12W-23N1 relative to those in wells 8N/12W-2Q1 and -10J1, 3 and 3.5 mi south, respectively, which are completed in the principal aquifer. Historical records indicate that heads in well 9N/12W-23N1 were similar to heads in wells 8N/12W-2Q1 and -10J1 in the late 1950's and early 1960's. The rate of head decline in wells 8N/12W-2Q1 and -10J1 slowed in the early 1970's and then leveled off in the early 1980's (Londquist and others, 1993, fig. 17). This leveling off corresponds to a decline in agricultural activities in the valley. Heads in well 9N/12W-23N1 continued to decline in the deep aquifer. In 1992, heads in well 9N/12W-23N1 were about 13 and 33 ft lower than those in wells 8N/12-2Q1 and -10J1, respectively (fig. 14). Lack of sufficient recharge, recharge capture, and increased pumping from the deep aquifer for public and industrial supply may explain the steady decline in heads in the deep aquifer. Continued monitoring and analysis of head levels in these wells may help determine the cause of the declining heads, as well as document short- and long-term changes in the aquifer system.

BASIN BOUNDARIES

Three types of no-flow boundaries have been identified for the aquifer system at EAFB: structural boundaries, a principal-aquifer boundary, and ground-water divides (fig. 3). A no-flow boundary is a specialized constant-flux boundary where flux is zero and is typified by a region across which ground water neither enters nor leaves the aquifer system. Structural boundaries are juxtaposed bedrock-alluvium or consolidated-unconsolidated alluvium. In the Lancaster subbasin near EAFB, flow in the deep aquifer is defined by structural boundaries and a ground-water divide. The principal-aquifer boundary is the contact between relatively thick, very fine-grained, low-permeability, lacustrine material of the confining unit and coarse-grained alluvium of the principal aquifer. The principal-aquifer boundary controls ground-water flow in the principal aquifer. The confining unit separates the principal and the deep aquifers of the Lancaster subbasin. Permeability contrasts across structural and principal-aquifer boundaries generally are greater than several orders of magnitude. A ground-water divide is a ridge of relatively high hydraulic heads in the aquifer along which hydraulic heads are equal and from which ground water flows in opposite directions. The ground-water divide controls ground-water flow in the deep aquifer between the Lancaster and North Muroc subbasins. Boundary conditions were determined using surface and borehole geophysical data, lithologic logs, and ground-water-level data. Table 4 lists the altitudes of the confining-unit interval and bedrock-alluvium contacts of the wells used in this study.

Structural Boundaries

The structural boundaries to the south and southeast of Rogers Lake and north of the Phillips Laboratory well fields (fig. 5) are bedrock-alluvium contacts. These boundaries were defined using isostatic residual gravity data (John Mariano, U.S. Geological Survey, written commun., 1991). Lithologic logs for wells 10N/8W-32R1 and 9N/8W-6J1 show

Table 4. Altitudes of confining-unit interval and bedrock-alluvium contacts for wells on and near Edwards Air Force Base, California

[State well No.: See well-numbering diagram on page V. See figure 5 for location of wells. Altitude of confining-unit interval and bedrock-alluvium contact in feet above sea level. (U.S. Army Corp of Engineers, 1961; Dutcher and others, 1962; Dutcher and Worts, 1963; Londquist and others, 1993; Rewis, 1993]

State well No.	Altitude of confining-unit interval	Altitude of bedrock-alluvium contact
8N/9W-6D1	2,137 - 2,247	
8N/10W-1Q1	2,052 - 2,212	
-1Q2	2,052 - 2,212	
-1Q3	2,052 - 2,212	
-1Q4	2,052 - 2,212	
-4R1	2,071 - 2,261	
-4R2	2,071 - 2,261	
-4R3	2,071 - 2,261	
-4R4	2,071 - 2,261	
-8J1[1]	1,991 - 2,100	
-17J2[1]	([2]) - 2,129	
-18N1[1]	([2]) - 2,059	
-19N2[1]	1,927 - 2,072	
-28A1[1]	([2]) - 2,083	
-30R1[1]	1,706 - 2,104	
8N/11W-9D1[1]	1,976 - 2,176	
-10E1[1]	1,937 - 2,274	
-22P2[1]	([2]) - 2,115	
8N/12W-13D1[1]	1,887 - 2,283	
-14R1[1]	1,911 - 2,291	
-24P1[1]	1,646 - 2,234	
9N/8W-6J1		2,024
9N/9W-6C1[1]		2.179
-6E1[1]		2,208
-6L1[1]		2,151
-9A1	2,196 - 2,271	
-9A2	2,196 - 2,271	
-28A1	2,186 - 2,271	
-28A2	2,186 - 2,271	
-28A3	2,186 - 2,271	
-28A4	2,186 - 2,271	
9N/10W-12R1[1]		2,032
-14C1[1]	2,218 - 2,204	2,204
-16F1		2,190
-16L3		2,073
-16N1		1,936
-24C1	2,193 - 2,238	
-24E1	1,788 - 1,822	
-25P1	2,169 - 2,269	
-27P1	2,239 - 2,278	
-27P2	2,239 - 2,278	
-28H3	2,277 - 2,288	2,025
-28H4	2,277 - 2,288	2,025
-34P3[1]	2,150 - 2,295	
-34R2	2,145 - 2,190	
-34R3	2,145 - 2,190	
-34R4	2,145 - 2,190	
-36J1	2,143 - 2,233	
-36J2	2,143 - 2,233	
-36J3	2,143 - 2,233	
-36P2	2,135 - 2,270	
9N/12W-26Q1[1]	2,171 - 2,284	
-28F3[1]	2,254 - 2,324	
10N/8W-32R1[1]		2,336
10N/9W-4D1	([2]) - 1,867	
-27C1	2,242 - 2,272	2,082
-27C2	2,242 - 2,272	2,082
-27C3	2,242 - 2,272	2,082
-31C1[1]		2,118
-31C4[1]		2,155
-31N1[1]		2,212

[1]Wells not monitored for this study.

[2]Altitude of lower contact unknown.

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bedrock altitudes of 2,336 and 2,024 ft above sea level, respectively (table 4). The difference in land-surface altitude between these two wells is about 56 ft (table 1); the difference in bedrock altitude is about 312 ft. This difference indicates a structural boundary, probably a fault, between these wells.

Isostatic residual gravity data also were used to define the structural boundary south of the Rosamond and Bissell Hills (fig. 3) (John Mariano, U.S. Geological Survey, written commun., 1991). This boundary strikes southwest-northeast from the eastern shore of Rosamond Lake to Buckhorn Lake and coincides with the northwestern boundary of the Antelope Valley Fault Zone defined by Gary Dixon (U.S. Geological Survey, written commun., 1993) (fig. 3). This boundary juxtaposes younger, more permeable alluvium on the south against older, less permeable alluvium on the north. Dibblee (1960) describes this older alluvium as a fanglomerate of early Pleistocene age.

The structural boundary extends across Buckhorn Lake and along the southeastern edge of Hospital Ridge and juxtaposes the granitic bedrock of Hospital Ridge against younger alluvium of the basin (Dibblee, 1960). Monthly heads in well 9N/10W-28F2 (fig. 11) were similar to heads in wells 9N/10W-16N1 and -16M1 (fig. 12) to the north, near the Graham Ranch well field, but were about 45 to 50 ft higher than those in piezometers 8N/10W-5A4, 9N/10W-27P3, -28H4 and -34R4 to the south and east (fig. 11), indicating well 9N/10W-28F2 is north of the structural boundary.

From Hospital Ridge, the structural boundary strikes northward (fig. 3), crosses the buried Bissell Hills-El Mirage Fault (Gary Dixon, U.S. Geological Survey, written commun., 1993) and then parallels exposed bedrock west of Rogers Lake. Lithologic logs indicate that the altitudes of the bedrock-alluvium contact in wells 9N/9W-6E1 and 10N/9W-31N1 are about 2,200 and 2,212 ft above sea level, respectively (table 4). The altitudes of the bedrock-alluvium contact for wells 9N/9W-6C1 and -6L1, 9N/10W-12R1, and 10N/9W-31C1 are about 2,179, 2,151, 2,032, and 2,118 ft above sea level, respectively. Wells 9N/9W-6A1 and 10N/9W-31C4 did not penetrate bedrock. The structural boundary is interpreted to be between wells 10N/9W-31N1 and 9N/9W-6C1, between wells 9N/9W-6E1 and -6L1, west of well 10N/9W-31C1, and northwest of well 9N/10W-12R1. The position of the structural boundary west and northwest of the North Base well field is unknown because of a lack of data.

Principal-Aquifer Boundary

The principal aquifer is defined primarily by the principal-aquifer boundary. This boundary is the contact between the principal aquifer and the underlying fine-grained confining unit (fig. 4) and part of a structural boundary. The confining unit is assumed to be relatively impermeable both laterally and vertically in relation to the aquifers. Ground-water-level data (table 2) and lithologic data (table 4) were used to determine the position of the principal-aquifer boundary (fig. 3). Wells 8N/10-8J1 and -18P3; 8N/11W-14R1 and -15Q1; 8N/12W-2Q1, -10J1, -24P1, -26F1, and -28D1; and 9N/12W-33P1, south and southwest of Rosamond and Buckhorn Lakes, were completed in the principal aquifer above or several feet into the confining unit and south of the principal-aquifer boundary. The deep aquifer is confined in this region. The confining unit is at or near land surface in wells or piezometers 8N/10W-4R1, 8N/11W-10E1, 8N/12W-13D1 and -14R1, and 9N/12W-26Q1 and -28F3. The altitude of the confining-unit interval in well 8N/10W-8J1 south of the principal-aquifer boundary was 1,991 to 2,100 ft above sea level; in piezometer 8N/10W-4R1 north of the principal-aquifer boundary, the altitude of the confining-unit interval was 2,071 to 2,261 ft above sea level (table 4). The bottom contact of the confining unit comes to the surface near the south-central part of Rogers Lake (fig. 3). North of the South Track well field, the deep aquifer of the Lancaster subbasin is considered unconfined.

Ground-Water Divide

A ground-water divide, oriented east-west across the north-central part of Rogers Lake (fig. 3), separates the Lancaster and North Muroc subbasins and prevents ground water from flowing northward into, or southward out of, the North Muroc subbasin. The location of this divide may not be static, but probably migrates north and south over time in response to seasonal and long-term changes in ground-water levels in the Lancaster and North Muroc subbasins. Heads in piezometers 10N/9W-27C1 and -27C2 were about 2,193 ft above sea level, about 5 to 9 ft higher than heads in piezometers 9N/9W-9A1 and -9A2 to the south and about 10 to 11 ft higher than heads in piezometers 10N/9W-10B1 and -10B2 to the north (fig. 6*K*-6*M*).

The ground-water divide corresponds to a bedrock ridge of unknown extent and depth buried under relatively thin alluvium and playa sediments (L.C. Dutcher, U.S. Geological Survey, written commun., 1959; Bloyd, 1967). Quartz monzonite is exposed at the playa surface of Rogers Lake in the southeast corner of T. 10 N., R. 9 W. (sec. 20) (Dibblee, 1960, pl. 8). The borehole for piezometers 10N/9W-27C1 through -27C3, about 1.5 mi east-southeast of the quartz monzonite outcrop, penetrated granitic bedrock at 190 ft below the playa surface (Rewis, 1993). Drill cuttings from depths greater than 190 ft below land surface were very fine- to very coarse-grained, very angular fragments of feldspar and quartz (Rewis, 1993). Interpretation of refraction data collected during a seismic survey near piezometers 10N/9W-27C1 through -27C3 indicated a near horizontal alluvium-bedrock contact about 200 ft below land surface (David Berger, U.S. Geological Survey, written commun., 1992). This alluvium-bedrock contact, a slow drilling rate, and borehole resistivity values greater than 150 ohm-meters (Rewis, 1993) corroborate the existence of a buried ridge and help to determine the lateral extent and depth of the ridge.

Contrary to the evidence mentioned above, an interpretation of data collected during a direct current resistivity survey on Rogers Lake near the ground-water divide indicates that the depth to high-resistivity bedrock materials is about 2,300 to 2,900 ft below land surface (Zhody and Bisdorf, 1991). This resistivity data suggests that the bedrock outcrop and the material encountered during drilling may be large granitic boulders in the alluvium, but does not explain the distinct and extensive seismic-velocity contrast at 200 ft below land surface. This contrast may result because the material below 200 ft is fractured, highly weathered, altered or saturated bedrock. The exposed bedrock in the surrounding area is extensively faulted and highly weathered, and there are volcanic and hydrothermal alterations of sediments and bedrock to the north of Rogers Lake, which could account for the lower resistivites of the material at depths.

The Graham Ranch well field (fig. 5) is south of the Bissell Hills and northwest of Hospital Ridge. Bloyd (1967) and Duell (1986) considered this area to be part of the deep aquifer in the Lancaster subbasin. The Graham Ranch well field is separated topographically from Rogers Lake by the exposed bedrock of Hospital Ridge. Land-surface altitudes in this well field are about 40 to 50 ft higher than the playa surface of Rogers Lake. The aquifer in the Graham Ranch well field is unconfined and probably is isolated from the deep and principal aquifers. Hydraulic heads are higher than those in the deep aquifer and lower than those in the principal aquifer. Heads range from about 2,200 to 2,215 ft above sea level (fig. 12). The boundaries of this basin are irregularly shaped bedrock-alluvium contacts. The altitudes of the bedrock-alluvium contact in wells 9N/10W-16F1, -16L3, and -16N1 are 2,190, 2,073, and 1,936 ft above sea level, respectively (table 4). Wells 9N/10W-16P1, -16L2, -16R1, and -16R4 were drilled deeper (table 1) (Dutcher and others, 1962; Londquist and others, 1993), not penetrating bedrock. The absence of bedrock in these four wells indicates the presence of a small, possibly narrow, down-dropped basin, or graben, with a minimum of 460 ft of normal slip. This graben may be the result of the release of extensional stresses related to the Antelope Valley Fault Zone (fig. 2).

The Antelope Valley Fault Zone is a zone of left lateral strike slip faulting, with oblique dip-slip down to the southwest (Gary Dixon, U.S. Geological Survey, written commun., 1993). For the depth and configuration of this basin, the reader is referred to Londquist and others (1993). Gravity and surface-resistivity data (Zhody and Bisdorf, 1990; J. Mariano, R.C., Joahens, and R.L. Morin, U.S. Geological Survey, written commun., 1991) indicate that there may be a hydraulic connection to the deep aquifer between the bedrock ridges, possibly through buried drainage channels, although this has yet to be verified (Londquist and others, 1993).

Water levels were used to identify a small north-south trending ground-water divide in the Graham Ranch well field near piezometers 9N/10W-16R1 through -16R3. The borehole for the piezometers was drilled to 960 ft below land surface and did not penetrate bedrock (Londquist and others, 1993). This ground-water divide is caused by two pumping centers around EAFB production wells 9N/10W-16P1 (C-3) and 9N/10W-16R4 (C-4).

SEASONAL POTENTIOMETRIC SURFACES

A potentiometric surface is defined as an imaginary surface represented by hydraulic heads in wells and piezometers completed in an aquifer. For a confined aquifer, the potentiometric surface is above the base of a confining unit and is represented by the level to which water would rise in an open well penetrating the confined aquifer. For an unconfined aquifer, the potentiometric surface is the water table where ground-water pressures generally are the same as atmospheric pressure. For the purposes of this study, the heads of perched aquifers were not used to define the potentiometric surfaces because the water is trapped above the true water table by a lens of material with low permeability.

The purpose of mapping potentiometric surfaces is to provide a visual interpretation of the areal extent and generalized ground-water-flow paths of the aquifer system. Hydraulic heads in EAFB production wells, abandoned wells, and one piezometer from each of the USGS piezometer sites were used to contour the potentiometric surfaces (figs. 15 through 18, at back of report). Table 5 lists the hydraulic heads and changes in head used in this interpretation. The head values were rounded to the nearest tenth of a foot.

Several factors were used in the determination of the potentiometric surfaces of the aquifer system at EAFB. Pumping centers on the base were identified. Domestic and public supply wells in and near the town of Rosamond (fig. 2) and agricultural irrigation wells south of Redman also were considered because of their influence on the ground-water-flow paths and changes to the potentiometric surfaces. To project contours south and west of the base boundary (figs. 15 through 18), hydraulic heads were calculated for the principal and deep aquifers using spring ground-water-level measurements (tables 2 and 5) for wells monitored by the USGS as part of the Antelope Valley-East Kern Water Agency ground-water-monitoring program.

Changes in the Potentiometric Surfaces

Changes in the potentiometric surfaces of the aquifer system at EAFB were relatively small in 1992. Hydraulic head contours for spring 1992 ranged from about 2,160 to 2,220 ft above sea level in the deep aquifer and 2,200 to 2,280 ft above sea level in the principal aquifer in the Lancaster subbasin; 2,180 to 2,190 ft above sea level in the North Muroc subbasin; and 2,210 to 2,290 ft above sea level in the Graham Ranch well-field area (figs. 3 and 15-18). Figure 19 shows contours for changes in hydraulic head for spring to late summer 1992 for wells completed in the deep aquifer (table 5). Changes in head for five wells completed in the principal aquifer (not illustrated) were less than 2 ft (table 5). Figure 20 is generalized geologic cross sections showing hydraulic heads in selected wells and piezometers for sections shown on figure 15.

Deep Aquifer

In the areas between and adjacent to the South Track, South Base, and Branch Park well fields, the potentiometric surface of the deep aquifer for spring 1992 ranged from 2,160 to 2,180 ft above sea level forming a shallow regional ground-water depression (fig. 15). This depression is oriented along a southwest-northeast trending axis similar to the trend of maximum measured subsidence reported by Londquist and others (1993, fig. 21).

In spring 1992, the deep aquifer was confined in the South Track well field. A small, shallow, local ground-water depression formed around well 9N/10W-34P3 in the Branch Park well field in response to pumping (table 3, figs. 15 and 20). In May, the South Track well field began pumping almost continuously. Between April and September, the potentiometric surface had declined about 10 ft in the South Track well field, about 3 ft in the South Base well field, and about 8 ft in the Branch Park well field (table 5, fig. 19). Because of a 10-foot decline in the potentiometric surface in the South Track well field by late summer and 20- to 30-foot drawdowns in production wells 8N/10W-1C2 and 9N/10W-36F1 and -36P1 (table 5, fig. 8), water-levels dropped below the bottom of the confining unit, which resulted in the deep aquifer becoming locally unconfined near the wells (figs. 8 and 20). The configuration of the potentiometric surface of the deep aquifer south and southwest of EAFB is unknown (figs. 15 and 16).

Change in hydraulic heads from spring to late summer in and near the Phillips Laboratory and North Base well fields were 0 to 2 ft and 2 to 3 ft, respectively (fig. 19). Heads near the ground-water divide